Human Performance Modeling Predictions in Reduced Visibility Operation With and Without the Use of Synthetic Vision System Operations

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Abstract

The San Jose State University human performance modeling team undertook this human performance modeling research effort to predict the performance of operators using the Synthetic Vision System (SVS), with support of the NASA Aviation Safety Program. Test scenarios were developed and procedures were established based on the NASA Ames part-task human-in-the-loop simulation for both the baseline (current technology) operations and the advanced SVS operations conditions. The aircraft performed approaches to landing at Santa Barbara Airport flying under Instrument Meteorological Conditions (IMC) with "current day" technologies or "future" cockpit configuration (SVS display). The Air MIDAS model was augmented to handle the flight procedures observed in the human-in-the-loop simulation. The standard Air MIDAS model of visual performance was augmented to include the affect of contrast legibility and visual search/reading time to account for performance using the synthetic vision system. After model development, a simulation test was run on approach under conditions of baseline, SVS, and SVS with sidestep maneuver required. High correlations were found between the modeled procedures and information-seeking behavior and that of the human operator's performance in simulation. The model's data were subjected to verification and validation analyses.

1. Introduction

NASA is developing a number of technologies designed to aid the flight crew in the safe operation of the aircraft under conditions that in the past have been shown to contribute to increased hazards in aviation operations. Those technologies have a common purpose in aiding the flight crew by providing information that has either been not available (e.g. improved traffic position information or rapid update of local meteorological conditions like turbulence) or has been obscured and degraded (e.g. visual acuity reduction in weather and at night). The advancements in computational techniques, sensor and communication technologies have resulted in an enviable design situation in which the amount and quality of information available is large and therefore must be carefully selected to avoid overwhelming the flight crew. Interesting issues of information selection, information integration requirements and display operation are open to investigation in the conceptual and early design stages of the systems development.

1.1 Synthetic Vision System

Recently, NASA has been developing augmentative technologies comprising a synthetic vision system (SVS) for commercial aviation as well as for business jets, and general aviation operations. The system is designed to generate a texture-mapped (or wire-frame) display of the terrain in proximity to the aircraft. Text and other symbology will be overlaid onto the terrain display to display, for instance, the aircraft itself, its velocity, a "follow-me" aircraft, a "tunnel-in-the-sky" indication of the route, and indications of other nearby aircraft. In addition, flight controls (air speed, attitude, pitch, etc.) will be overlaid on the display. A more complete review of the several designs under development for the support and provision of synthetic vision can be found in Corker & Guneratne (2002). In addition, the existing display elements of current aircraft will be maintained in an SVS-equipped aircraft. Providing both of these sources of information may be problematic. On one hand they support cross checking of flight deck systems, on the other hand two sources of information that are similar in source and content, but different in presentation mode may cause transformation workload for the pilot. When systems such as the one being proposed for the SVS are being designed, we suggest that, in early design phases, computational human performance models can be used to predict various performance effects of introducing such augmented technologies.

2. Human Performance Modeling

The use of the human performance modeling methodology has been suggested as an effective means to study concepts in complex systems or those designs that are very early in their design phases (National Academy Press, 1990). In the type of human performance modeling undertaken in this study, the parameters of human behavior embedded within the model framework are based on empirical research in both basic and applied human performance. The modeled operator is then set to interact with computer-generated representations of the operating environment over a series of repeated runs in much the same manner as testing human subjects over repeated experimental sessions. Elements of the human performance model (for example, performance time for a particular task) can be made a stochastic variable and their values can fluctuate across these multiple runs. The model of human performance enables predictions of behavior based on elementary perception, attention, working memory (WM), long-term memory (LTM) and decision-making models of human behaviors. This modeling approach focuses on micro models of human performance that feed-forward and feedback to other constituent models in the human system depending on the context and on mission needs and requirements.

Human performance models have produced validated predictions of human performance within complex operating environments ranging from highly advanced military systems (Atencio, 1998; 1994), nuclear power plan operations (Corker, 1994), and advanced concepts in aviation (Corker, Gore, Kennedy & Lane 2000). In this study, the human performance modeling software tool, Air Man-machine Integration Design and Analysis System (MIDAS), was used to generate predictions of human performance using the synthetic vision system (SVS).

2.1 Air MIDAS

The Air MIDAS software (a NASA Ames Research Center, San Jose State University development effort) is a performance prediction software tool that uses models of human performance within an integrated computational framework to generate workload, and activity timelines in response to operational environments (Gore, 2002).[1] The main components of the model exercised in this study were the simulated operator's world representation, and the symbolic operator model (SOM) representing perceptual and cognitive activities of an agent. In the SOM, the Updateable World Representation (UWR) contains information about the environment, crew-station, vehicle, physical constraints and the terrain. Updates of the states of these elements are provided through the perceptual and attention processes of the SOM. The world representation serves to trigger activities in the simulated operator to serve mission goals or respond to anomalies. The UWR also contains the WM of the simulated operator, the domain knowledge, and a goal-based procedural activity structure. Activities to be performed are managed through a queuing process and scheduled according to priority and resource availability. Four resource pools (Visual, Auditory, Cognitive, and Psychomotor) are checked for resource availability in response to the demands for those resources by the required tasks (McCracken & Aldrich, 1984). Figure 1 outlines the model organization and flow pattern associated with information entering into the modeled operator.

[1] For a complete review of the Air MIDAS model see Corker (2000).

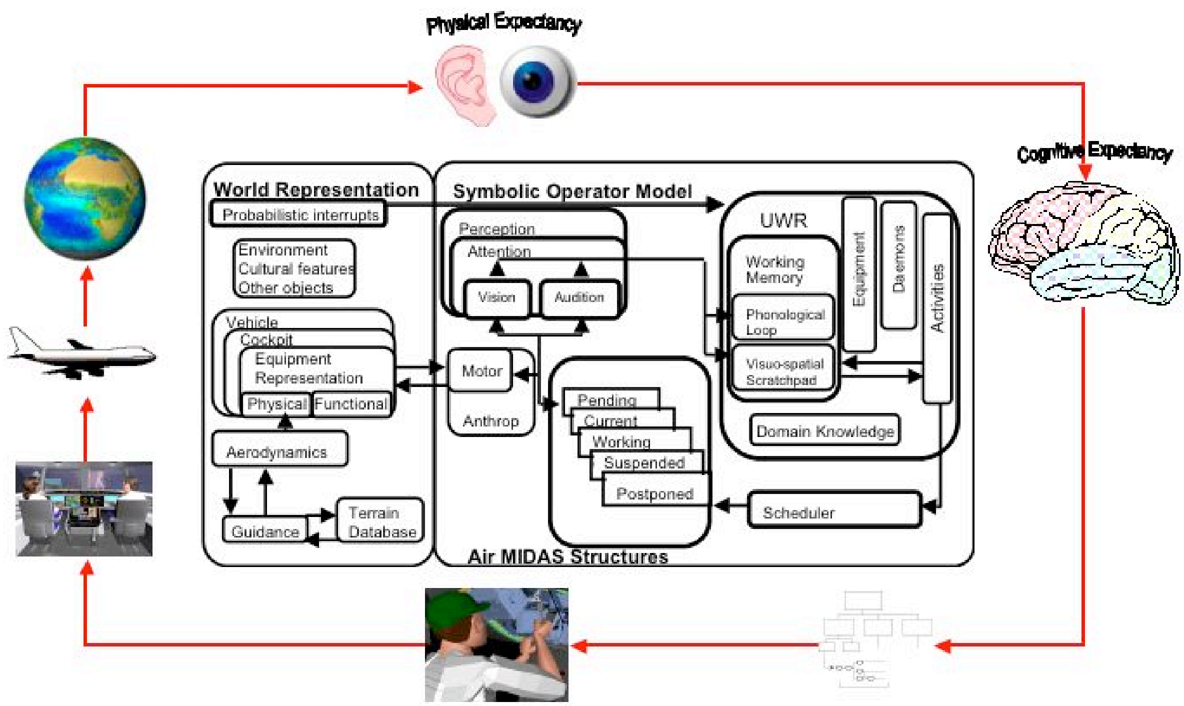

Figure 2. Air MIDAS Structure and Control Flow (from Gore, 2003).

Visual information such as that provided by the SVS or the out the window information is perceived and attended by the Air MIDAS operator. This external information is passed into the Symbolic Operator Model (SOM) through its attention and perception models. Once this information is perceived, it is passed into the Updateable World Representation (UWR) structure that contains the WM, phonological loop, a visuo-spatial scratchpad, rules for invoking and retaining memory information and the domain knowledge of the condition surrounding the operator.

In the SVS example, the operator perceives, for instance, descent-related information either from instruments or from the out-the-window view. These data trigger a series of rules to satisfy flight goals. In the case under study here, perceptual processes associated with the SVS system and/or the out-the-window observation are critically important. Their development is described below.

2.2 Air MIDAS Visual Perception Model

Perception in the Air MIDAS model proceeds by initiation of a visual activity (e.g. scan-instruments) that updates information in MIDAS every 'tick' (a 100 ms time increment). In support of the SVS experiment, the Air MIDAS perceptual process was enhanced.

In keeping with an approach to landing under both visual and instrument meteorological conditions, the Air MIDAS perceptual functions were developed to include in-cockpit scanning, both with and without the display augmentation of the SVS system. In addition, we included an out-the-window visual capture model for detecting features, aircraft stability, heading and position, associated with decisions on approach. The equipment representation and visual perception were refined to include the behavior of a human operator interacting with display technologies on which various electronic visual enhancements (e.g. runway center and sidelines) were contained.

2.3 Visual Perception Process

The human-in-the-loop eye fixation data for the baseline condition was compared with the model eye fixation for the baseline condition. The scan patterns of baseline condition were created using data adapted from Mumaw et al. (2000). The human-in-the-loop eye fixation data for the SVS condition was compared with the fixation data on the same scenario generated by the model. In generating the predictions of fixation pattern in the MIDAS software, it was expected that the SVS display would replace the out-the-world fixation times and that fixation on the SVS display would be followed by fixation on the PFD. To incorporate the SVS into the scan pattern of the flight crew, the OTW percentages were replaced by SVS scans. A description of each of the individual components as numbered in Figure 2 will be described below.

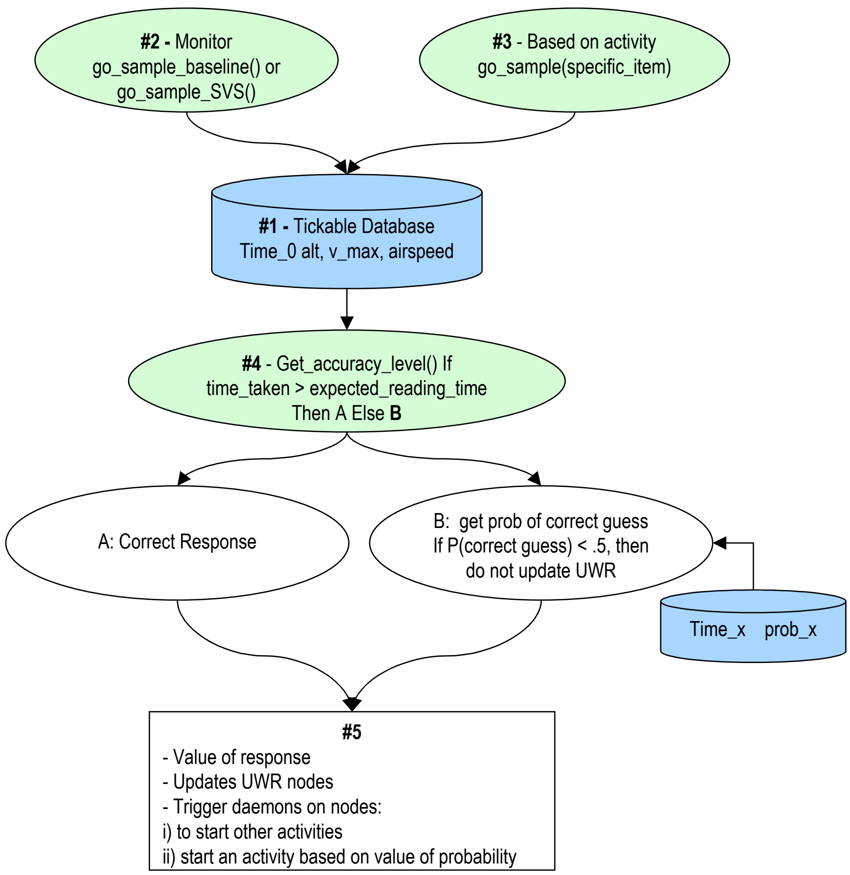

Figure 3. Flow of information for Vision Model.[2]

2.3.1 Component #1 – Flight Information Database

The database was designed to follow an incremental 100 ms update sequencing as visual perception activities are performed. Equipment components were incorporated in the simulation to provide the Air MIDAS operator with required flight-related information. These included the Primary Flight Display (PFD), the Mode Control Panel (MCP), the Navigation Display (ND), the out the window

[2] Components #1 through #5 are described below.

scene, the Synthetic Vision System (SVS), and other flight control information such as the flaps, the throttle and the speed brake controls.

A database was created to provide a shared database between the two Air MIDAS flight crew operators. The PFD provided the Air MIDAS operator with altitude, airspeed, attitude, heading, and the flight mode enunciator. The MCP provided the vertical speed, the MCP altitude and the MCP altitude dial. The ND information provided the aircraft true heading information. The OTW provided the simulated world landing information. The SVS provided the augmented display technology to enhance flight crew situation awareness on approach in instrument landing conditions. Some software daemons (responding to critical parameter values) were also incorporated based on the UWR nodes that got triggered.

2.3.2 Component #2 – Monitor – "Go_Sample" Baseline

As represented in Figure 2 through the monitoring node and Figure 3 through the detailed description of the go-sample structure, information from the database flows into the Air MIDAS operator through the augmented visual system. The baseline scan pattern was developed and used for the non-SVS scenario. Modifications were made to the scan pattern for the SVS scenario. Figure 3 represents the information flow.

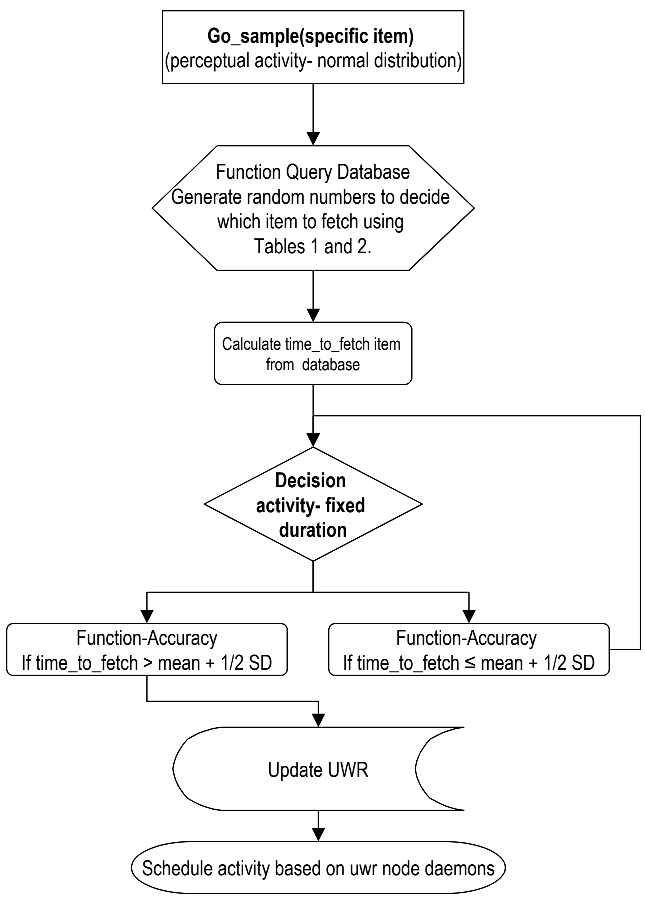

Figure 4. Flow of information when scan patterns are implemented.

The normal internal scan pattern and dwell time was based on NASA's report on the Analysis of Pilot's Monitoring and Performance on Highly Automated Flight Decks generated by Mumaw et al., (2000). These data can be found in Tables 1 and 2 below.

Table 2. Internal Dwell Time Percentages and Locations during VNAV Descent.

	Percentage Dwell	**Proportion**	Mean Dwell Duration (sec)
PFD	32% (32/82)	**0.39**	0.68
ND	33%	**0.40**	1.75
MCP	3%	**0.04**	0.72
Out of Window	1%	**0.01**	1.38
Other	13%	**0.16**	2.00
Total	82%		

Table 3. PFD Area of Interest (AOI) Percent Dwell Time for VNAV descent.

	Percentage Dwell	**Proportion**	Mean Dwell Duration
PFD airspeed	22%	**0.27**	0.68
PFD attitude	28%	**0.34**	0.54
PFD altitude	24%	**0.29**	0.59
PFD heading	3%	**0.04**	0.44
PFD FMAs	5%	**0.06**	0.41

The Air MIDAS model operates according to a sampling activity to obtain the information from the world. The gaze location is based on the proportions from Tables 1 and 2 above. The sampling activity for the SVS involved a scan of different equipment components. These included the third component called the "go-sample (specific target)" search pattern.

2.3.3 Component #3 - Details on go_sample (specific target)

Data from eye movement planning research suggests that humans perform a sample activity whenever an activity demands it. The "go_sample (specific target)" activity gets triggered whenever an activity requires current visually-provided information for its performance. Figure 4 below demonstrates the flow of information for the "go_sample" activity.

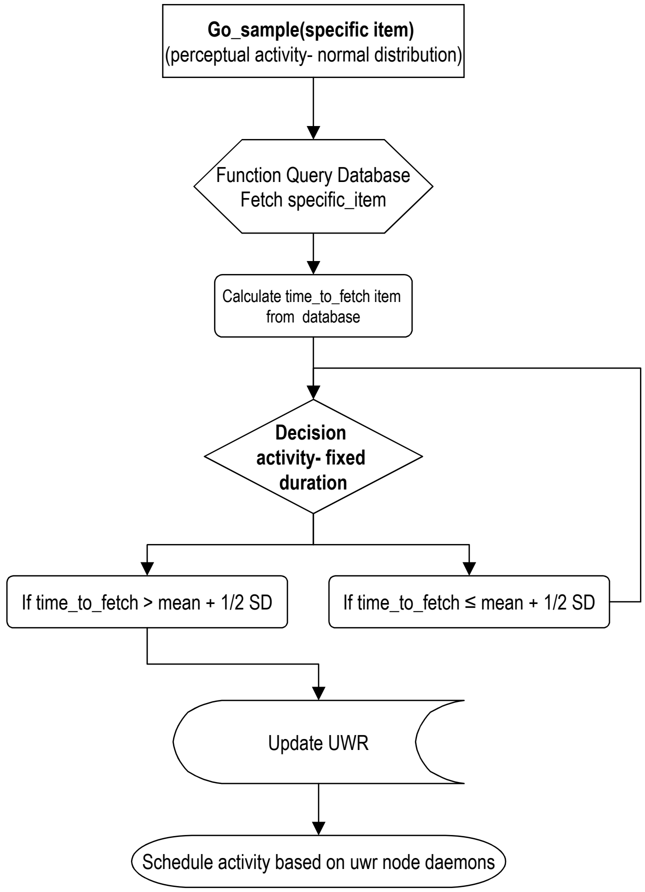

Figure 5. Flow of information when Go-sample (specific_item) is implemented.

2.3.4 Component #4 - Details on Accuracy Function

Information flow/sequence is only one part of the visual system that needs to be understood when explaining the process behind information uptake into the model representation. There are two other principal functions at work in information uptake, the expected reading rate and the accuracy functions.

2.3.4.1 Expected Reading Rate

The fixations associated with reading information from normal instruments should last a minimum of 200 ms (Landy, 2002). Visual fixations that move from an inside fixation to an outside fixation were increased by 500 ms to adjust for accommodation in the expected reading time. These considerations provide a reading time per character of 244 ms.

2.3.4.2 Accuracy Function

Table 3 (below) provides the mean, SD, min and max values of dwell duration for the Vertical Navigation portion of the descent phase of flight. This phase of flight possesses certain characteristic and required scan patterns and information searching behaviors of the flight crew's visual system. The data outlined below were used for building the accuracy function within the model's visual system.

Table 4. VNAV Descent Phase Data.

	MEAN	SD	MAX	MIN
Off AOIs	2.00	0.89	3.61	0.72
Out Win.	1.39	0.70	3.38	0.62
MCP	0.72	0.20	1.09	0.35
ND	1.75	0.47	3.08	1.16
CDU	1.63	0.60	2.67	0.80
PFD	0.68	0.11	0.90	0.50
PFD-ATT	0.40	0.26	0.82	0.00
PFD-Roll	0.44	0.33	1.34	0.00
PFD-Pitch	0.37	0.28	1.15	0.00
PFD-AS	0.68	0.40	1.41	0.00
PFD-ADI	0.54	0.29	1.04	0.00
PFD-ALT	0.59	0.31	0.90	0.00
PFD-HDG	0.44	0.27	1.08	0.00

Table 3 outlines the time associated with the situations when the visual scan is: (i) not fixated on anything in the cockpit or outside of the cockpit (Off AOI), (ii) when the fixation is out the window (Out Win), (iii) when the fixation on the MCP, (iv) when the fixation on the ND, (v) when the fixation on the Control Display Unit, and (vi) when the fixation on the various PFD readings. The decision to update the world representation of the Air MIDAS operator ("update_uwr") is based on the logic that states "if time_to_fetch item > Mean + 1/2 SD then update uwr, else do not update uwr". The assumptions associated with this exponential function can be found in Figure 5.

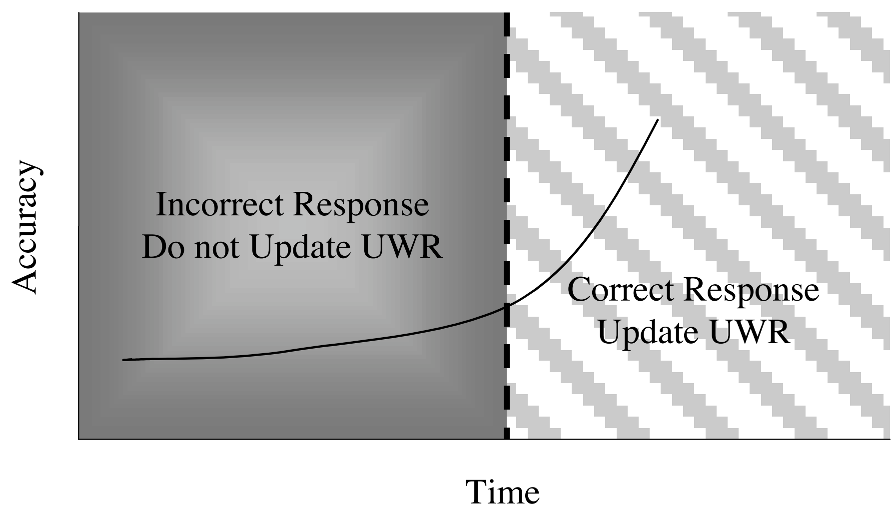

Figure 6. Accuracy function assumed as an increasing exponential function.

3. Simulation Experiment

An experiment was conducted to evaluate the impact of the synthetic vision system on information seeking and on flight procedures in an approach to landing both with and without the SVS system.

3.1 Participants

No human subjects were used in the current Human Performance Modeling simulation project. Human performance data came from the prior part-task simulation of the NASA HPM Organizing Team (Goodman, Hooey, Foyle, & Wilson, 2003). All perceptual model data came from either existing micro models within Air MIDAS (visual perception model - Remington, Johnston & Yantis, 1992; visual processing and field of view information – Arditi and Azueta (1992); Lubin and Bergen (1992) or from research conducted by Landy (2002). All procedural timing data came from tables of human performance load values based on the McCracken and Aldrich scales of procedural performance loads (McCracken & Aldrich, 1984), procedural specifications came from discussions with Subject Matter Experts (SMEs) provided by the HPM Organizing Team. Two flight crewmembers were modeled in this effort, the captain and the first officer and 5 runs were completed for each of the blocks as per the research design denoted in Table 4 below.

3.2 Apparatus

This computational human performance model, Air MIDAS, generated predictions of the operator's performance with the SVS technologies being introduced into the cockpit. Air MIDAS operates on a SGI IRIX 6.2 platform on a SGI Indy (R5000) workstation containing 96 Megabytes of Random Access Memory (RAM). Air MIDAS also operates on a Windows NT platform with minimum 96 MB of RAM.

3.3 Procedure

The experiment was conducted using the design illustrated in table 4. Based on the NASA HPM Organizing Team's prior simulation runs, we selected three of the scenarios (denoted in **bold** in Table 4 below) to exercise our model.

Table 5. NASA SVS simulation variables: Bold denotes Team HAIL scenarios modeled.

		Current Day	**Current Day Display**	**Future SVS Display**
		Good (VMC)	**Low Visibility (IMC)**	**Low Visibility (IMC)**
Approach Event	**Nominal Approach (nominal landing)**	*Scenario #1*	**Scenario #4**	**Scenario #7**
	Late Reassignment (side-step & land)	*Scenario #2*		**Scenario #8**
	Missed Approach (go-around)	*Scenario #3*	*Scenario #5*	*Scenario #9*
	Terrain Mismatch (go-around)		*Scenario #6*	*Scenario #10*

The nominal approach refers to the normal aircraft descent approach pattern with no deviation in flight plan to the runway surface. The late re-assignment approach refers to a request by Air Traffic Control for the aircraft to modify the approach plan and land the aircraft on a parallel runway. The current-day display refers to the current cockpit configuration when the aircraft is on the approach and landing phase of flight. The future SVS display refers to the display augmentations and resultant procedural changes associated with SVS operation. The visibility classification of either "good" or "low" refers to the degree to which the flight deck could see the external environment and the runway. Good visibility meant no visibility limitations while the low visibility meant no visibility until the aircraft broke through the cloud cover at 800 feet, very close to the existing minimum altitude decision height required for aircraft landing. The scenario numbers are the scenario numbers that were utilized by the NASA Organizing Team as a means of identifying the scenario for appropriate data collection.[3]

Figure 6 below outlines the RNAV (GPS) aircraft approach path, the altitude relative to the runway, the environment, and the decisions and responses necessary for safely landing a Boeing 757 aircraft during nominal operations. The RNAV procedures that were generated for the SJSU HPM simulation used information provided by the NASA Organizing Team as well as information from Boeing Subject Matter Experts (SMEs). These baseline procedures were then modified to include the SVS within the internal scan process of the flight crew. The performance of the modeled flight crew was measured in terms of event sequences, fixation patterns and workload estimates. The performance of most interest here is the performance of the model compared the performance of the human-in-the-loop simulation tests.

Rules to guide model behavior were developed based on the procedures required for approach and landing. These rules/priorities were:

1. Altitude information update is a priority in information seeking,
2. 500 foot altitude is always signaled and all scans below 500 feet are always an out the window scans,
3. Crosscheck between the crew-members always occurs.

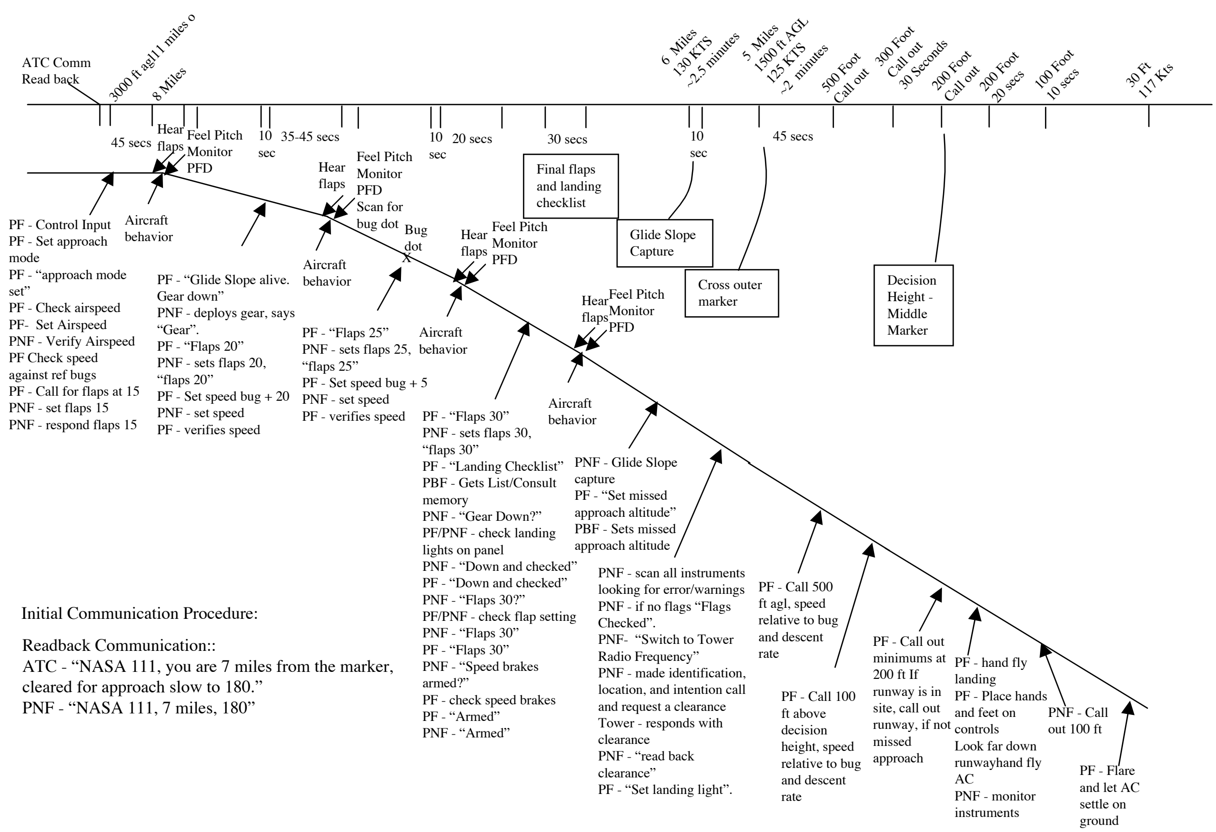

Figure 7. Procedural Sequence as Aircraft Approaches Santa Barbara Airport.

[3] For a more detailed description of the scenarios completed in the NASA SVS Simulation please consult Goodman, Hooey, Foyle, & Wilson (2003).

3.4 Data Collection

Data were collected at 100 Hz and post-processed by mapping to the event sequences in the simulation. The data were collected from the Final Approach Fix (FAF) to just before aircraft touch down. The data of interest were those associated with the point of aircraft break out, crew response time to the information in the simulated environment, and the procedural sequences associated with descent. The model was run under normal and low visibility conditions, both with and without the SVS, and either requiring or not requiring a sidestep maneuver. Five simulation runs were completed for each of the scenarios.

3.5 Results

The baseline runs served two purposes. First, we were interested in assuring that the model's operation produced data consistent with human performance in a baseline model, verification; and, second, that the verified baseline produced data that was predictive of human performance under new operational conditions, validation (Law & Kelton, 2000; Balci, 1998).

3.5.1 Fixation Frequency Analysis

Verification simulation trials on approach under (i) baseline without SVS, (ii) baseline with SVS and (iii) sidestep with SVS were conducted. As the data against which the verification was conducted did not reflect SVS use, assumptions as to the informational equivalence of out-the-window information seeking and SVS use were made. A strong correlation was found between the Mumaw et al.'s (2000) percent of fixations data and the Air MIDAS data across all scenarios. The correlation coefficients are as follows: (i) baseline (without SVS and with direct comparison to the source data) $r^2 = 0.9936$l; (ii) operation with SVS $r^2 = 0.9955$; (iii) SVS with sidestep $r^2 = 0.9948$. Figures 7 and 8 demonstrate the respective elements within the flight crew agent's scan pattern of the crew station and external environment. These data indicate that the procedural and visual sampling behavior largely replicate the source data of human performance. This is verification that the model behaves as designed and doesn't corrupt the seed human performance data.

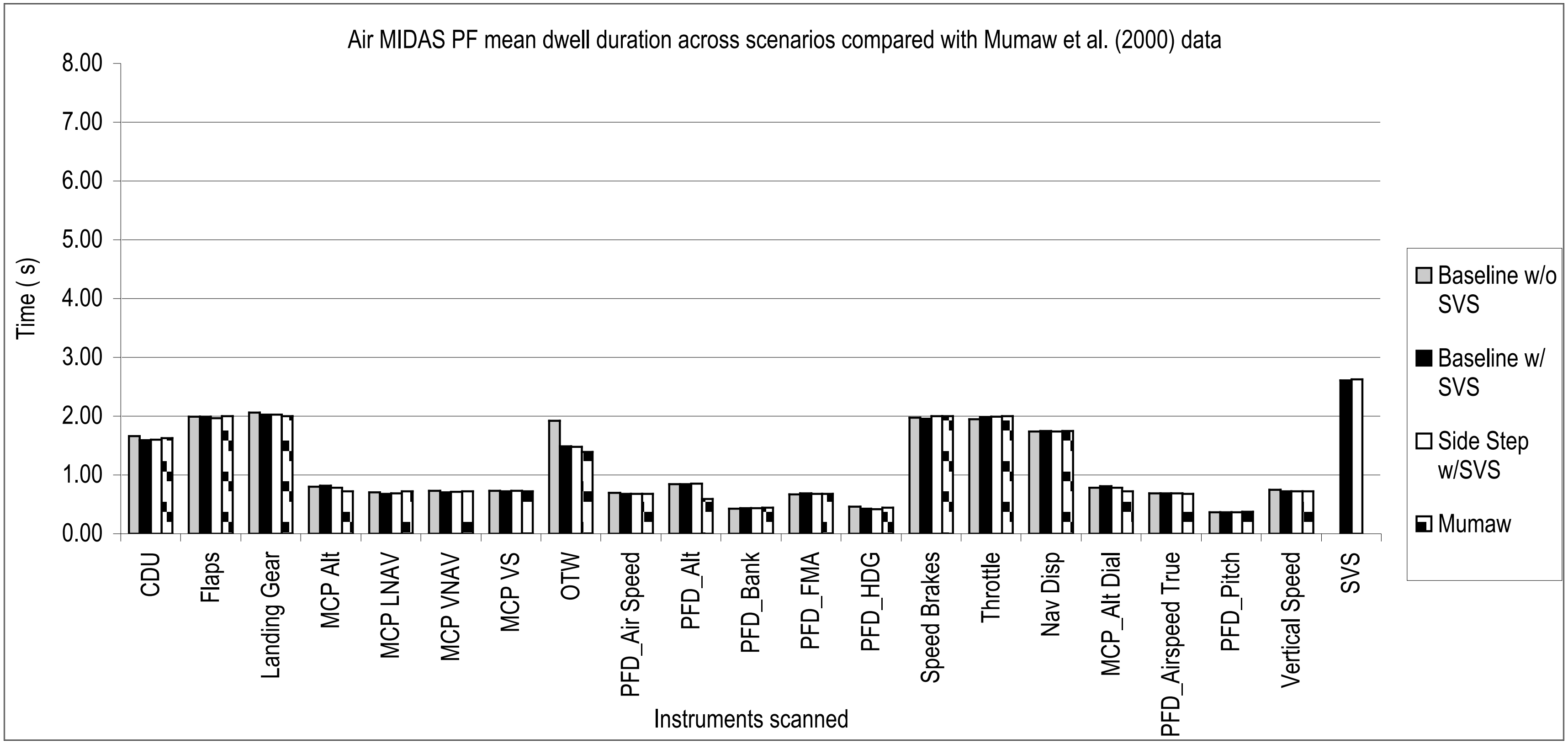

Figure 8. Air MIDAS mean Pilot Flying (PF) dwell duration compared with Mumaw et al. (2000) HITL data across scenarios.

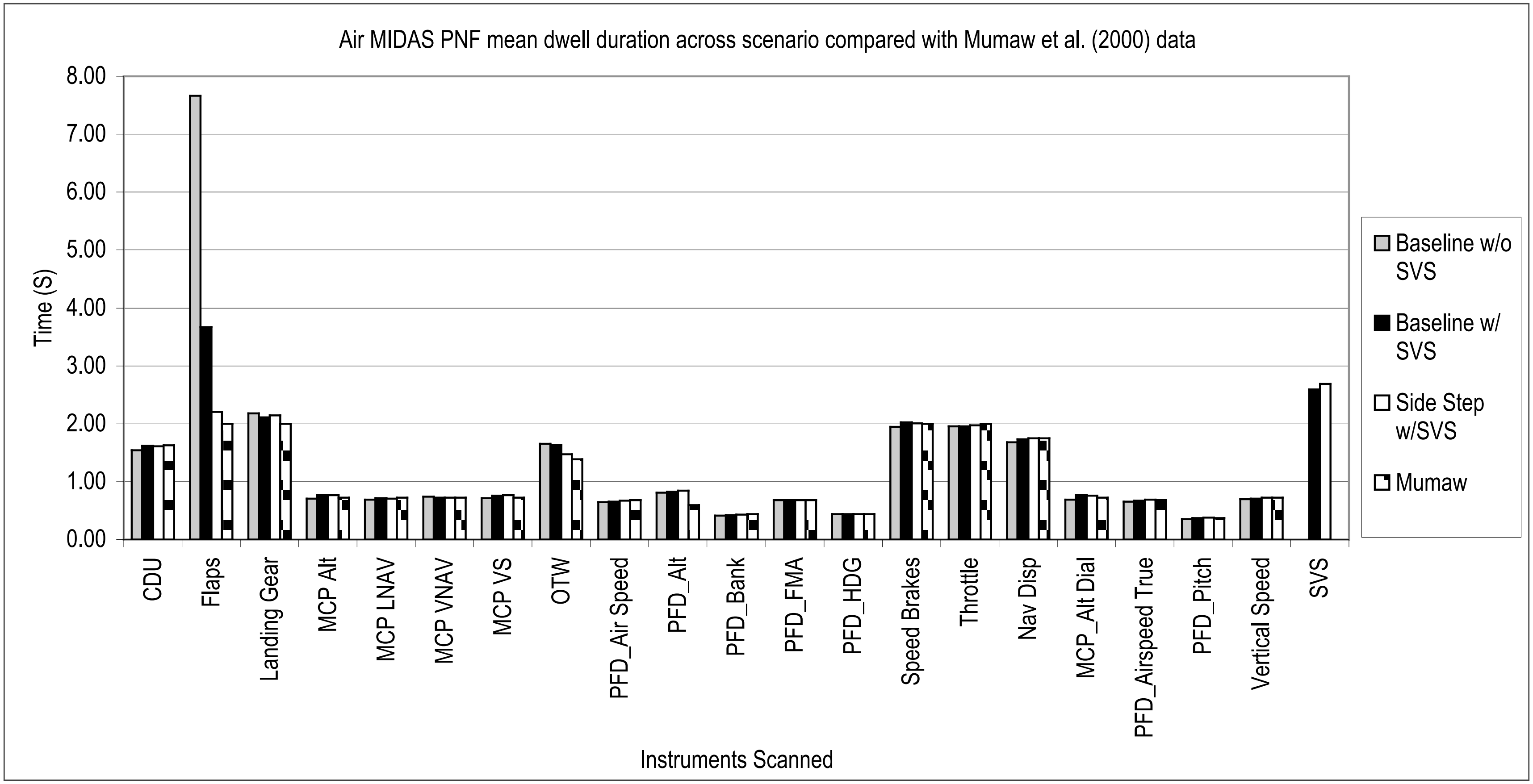

Figure 9. Air MIDAS mean Pilot Not Flying (PNF) dwell duration compared with Mumaw et al. (2000) HITL data across scenarios.

The predictive validity of the Air MIDAS model was also tested by running the model through three simulation conditions based on those undertaken in the NASA part-task experiment. Validation of the model's visual scanning behavior was examined by comparing model-generated dwell frequency to the human flight crew dwell frequency. The correlations between the NASA part-task simulation and the Air MIDAS data are as follows: (i) baseline $r^2 = 0.7608$; (ii) with SVS operation $r^2 = 0.~8782$; and (iii) SVS with sidestep $r^2 = 0.~5538$. An examination of each of the respective model-human dwell percentage locations comparisons by scenario can be found in the following three figures.

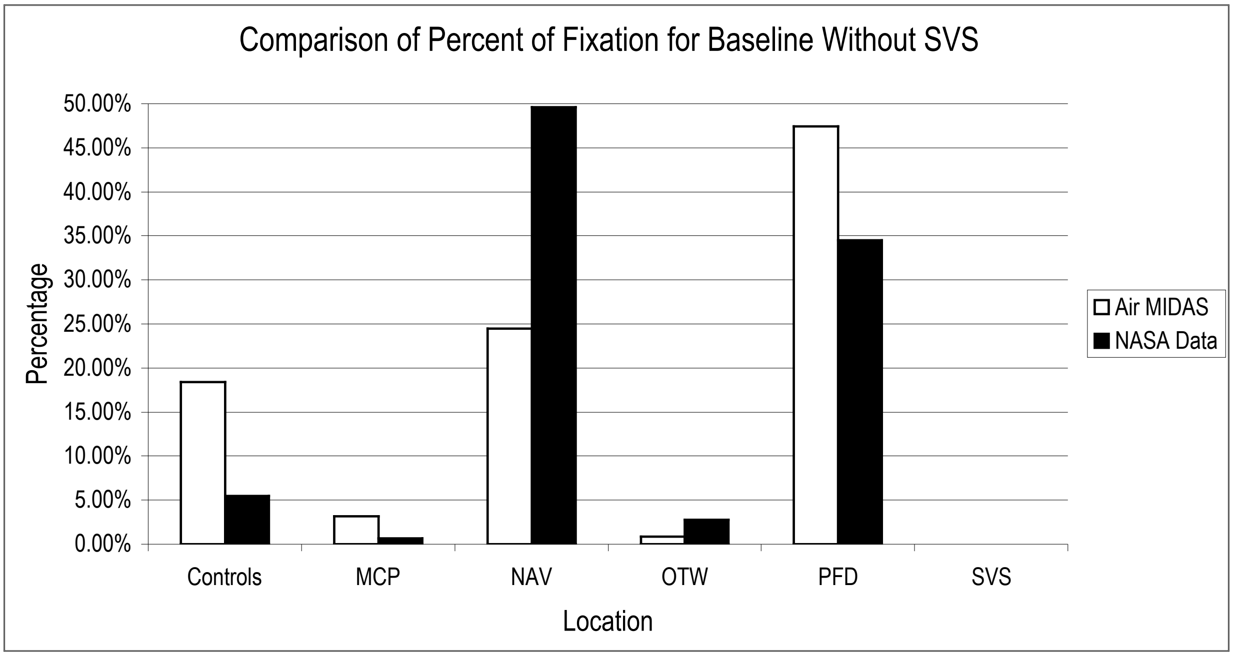

Figure 10. Model-Human Comparison of Baseline (no SVS) Fixation Percentage Location.

Figure 9 illustrate that the Air MIDAS model predicted slightly higher fixation on the controls, the MCP and the PFD than did the human data produced by Goodman, Hooey, Foyle, & Wilson (2003). The Air MIDAS model predicted lower dwells on the ND and the OTW scene than did Goodman, Hooey, Foyle, & Wilson (2003). This suggests that the rules guiding human performance are different than those guiding the model's performance. We might infer that the flight crew relies more on the information on the ND than does the Air MIDAS flight crew. Also, the Air MIDAS pilot fixated more on the PFD than does the NASA pilot (Goodman, Hooey, Foyle, & Wilson, 2003).

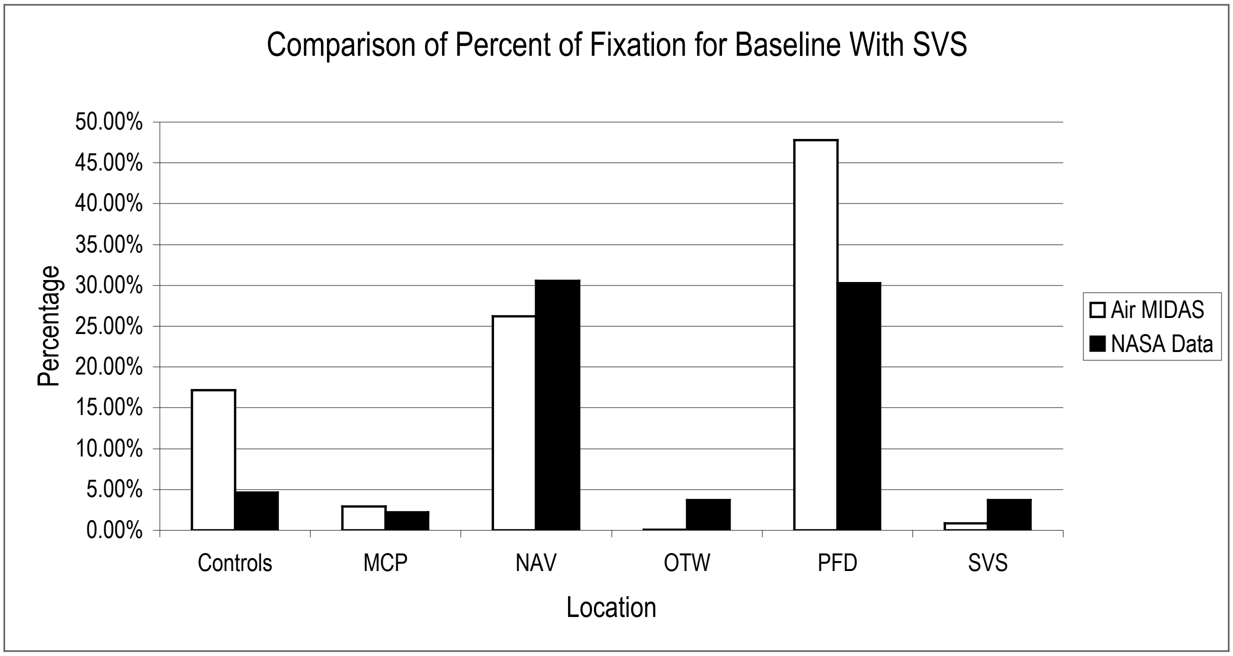

Figure 11. Model-Human Comparison of Baseline (With SVS) Fixation Percentage Location.

Figure 10 illustrates that the Air MIDAS model predicted slightly higher fixation on the controls, the MCP and the PFD than were observed by Goodman, Hooey, Foyle, & Wilson (2003). The Air MIDAS model produced lower dwells on the ND, the OTW scene and the SVS displays than did Goodman, Hooey, Foyle, & Wilson (2003).

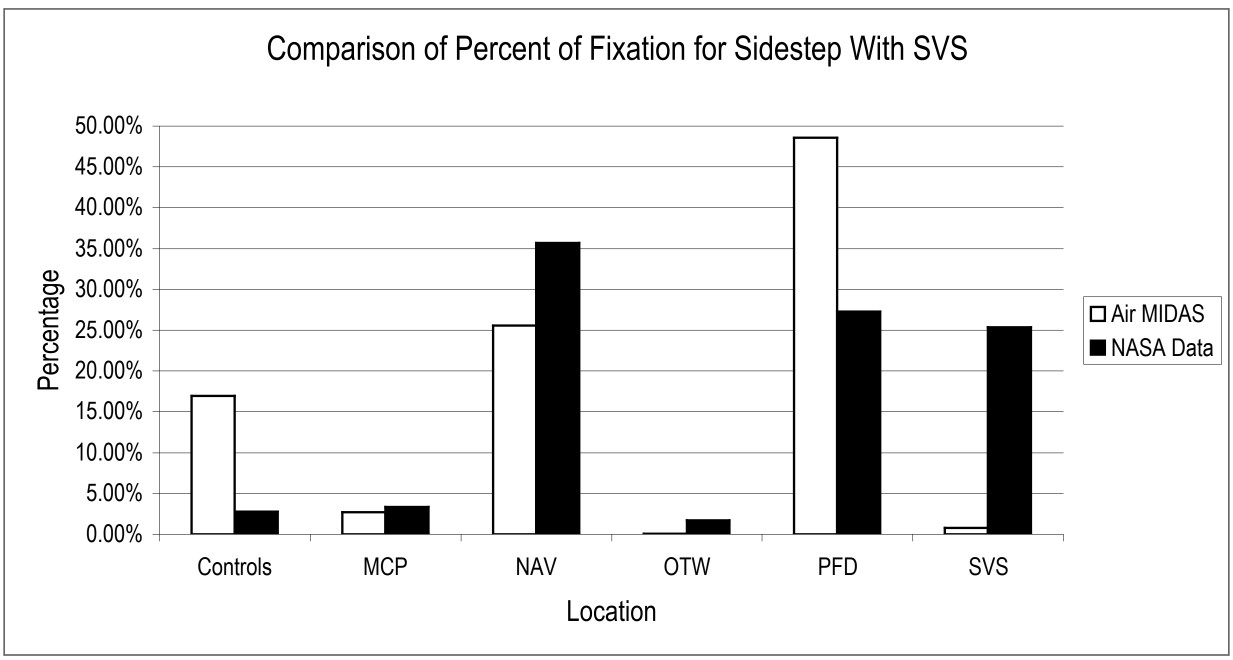

Figure 12. Model-Human Comparison of Sidestep (With SVS) Fixation Percentage Location.

The correlation of dwell time performance between human and model is lowest in the sidestep maneuver scenario as demonstrated in Figure 11. This is expected as the sidestep maneuver was least like the model baseline parameters. The kinds of information needed to support the sidestep and its implementation in SVS will need to be more closely examined in the next phase of research to better tune the model performance and dependence on the SVS system.

3.5.2 Procedural Activity Examination

Air MIDAS activities are structured in a hierarchy with goals, at the highest level of that hierarchy, being decomposed to sub-goals, and finally activities to produce the behavioral trace. We provide the goal sequence analysis to illustrate the differences in goal order between the scenarios run by the model. We compare the model-generated order to a “nominal goal ordering” based on established approach procedures.

The following figures demonstrate the order for the goals for both the pilot flying (PF) and the pilot not flying (PNF) throughout the three scenarios that were run. Figure 12 provides an outline of the predicted-operator-goal’s performance in the ‘Baseline without SVS condition’ (Scenario 4) and provides some insight into the active goals that are being completed by the respective agents (PF or PNF) relative to the nominal baseline performance. For example, it can be seen that there is a different behavioral pattern associated with the localizer capture callout in Figure 12. The PF performs this task quickly and similar to the performance expected during the nominal condition while the PNF is unable to complete this procedure due to the unavailability of resources. This results in a longer time to completion by the simulated PNF and could highlight a potential vulnerability in system performance if procedural requirements are added to the PNF at this time. Figure 13 illustrates the model’s predictions for procedural performance in the SVS operation and Figure 14 illustrates the model’s predictions for the Air MIDAS operator’s procedural performance in the SVS with sidestep scenario.

Nominal tasks	Pilot Flying	Pilot Not Flying
1	1	1
2	2	2
3	3	3
4	4	4
5	5	4
6	6	5
7	6	6
8	7	6
9	7	7
10	8	9
11	9	11
12	10	10
13	10	12
14	14	13

1. Set Precision FMS approach
2. 2500 callout
3. GS captured callout
4. LOC captured callout
5. Outer marker Callout
6. Final Descent Checklist
7. Receive ATC Clearance for runway
8. Check Procedure Turn
9. 1000 ft Callout
10. Set Flaps 30
11. 500 ft Callout
12. 100 ft above Decision Height Callout
13. Decision Height Callout
14. Check for stability and decide to land or go-around

Figure 13. Goal Order for Pilot Flying and Pilot Not Flying in the Baseline without SVS condition (Scenario 4).

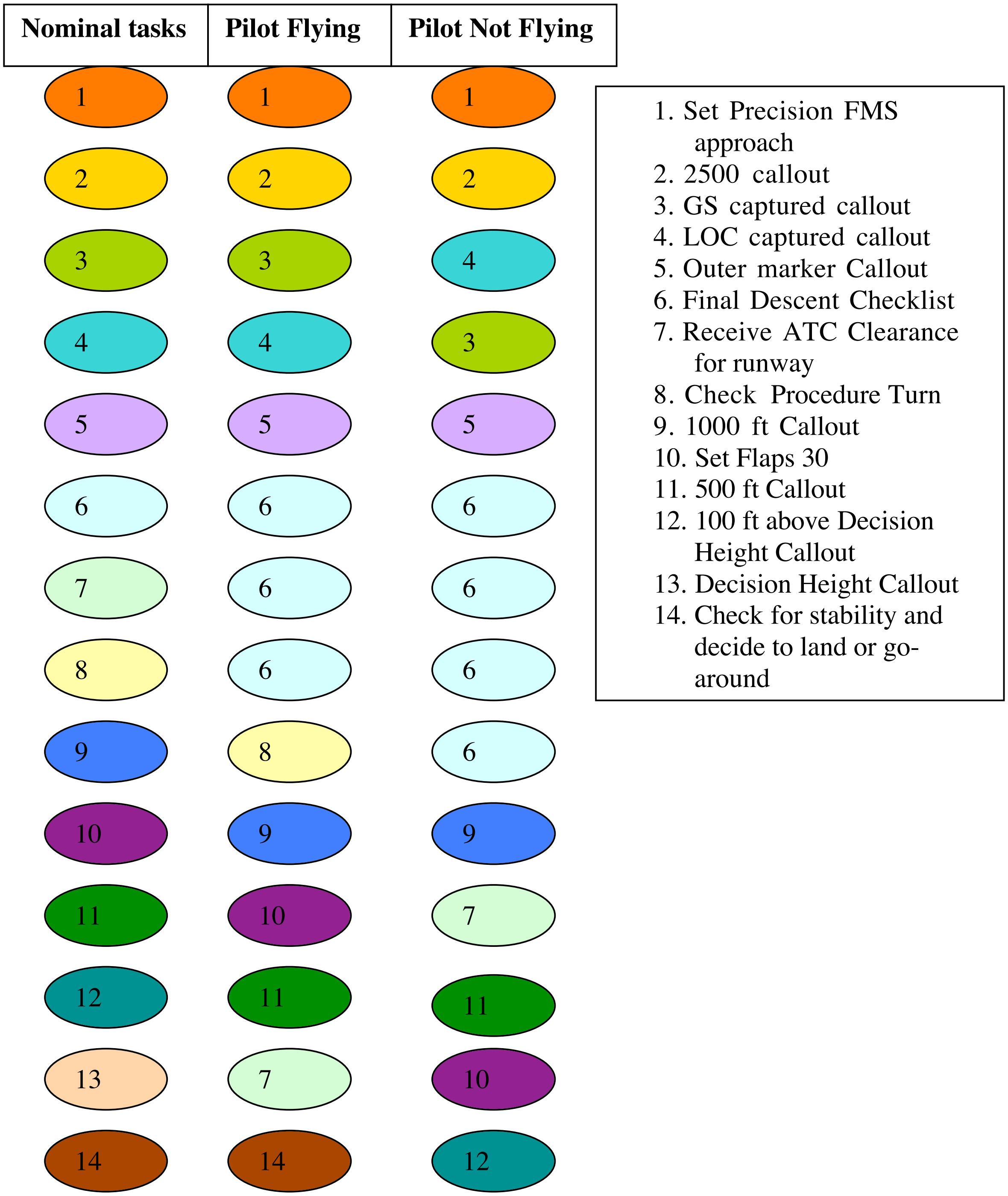

Figure 14. Goal Order for both Pilot Flying and Pilot Not flying in the Baseline with SVS condition (Scenario 7).

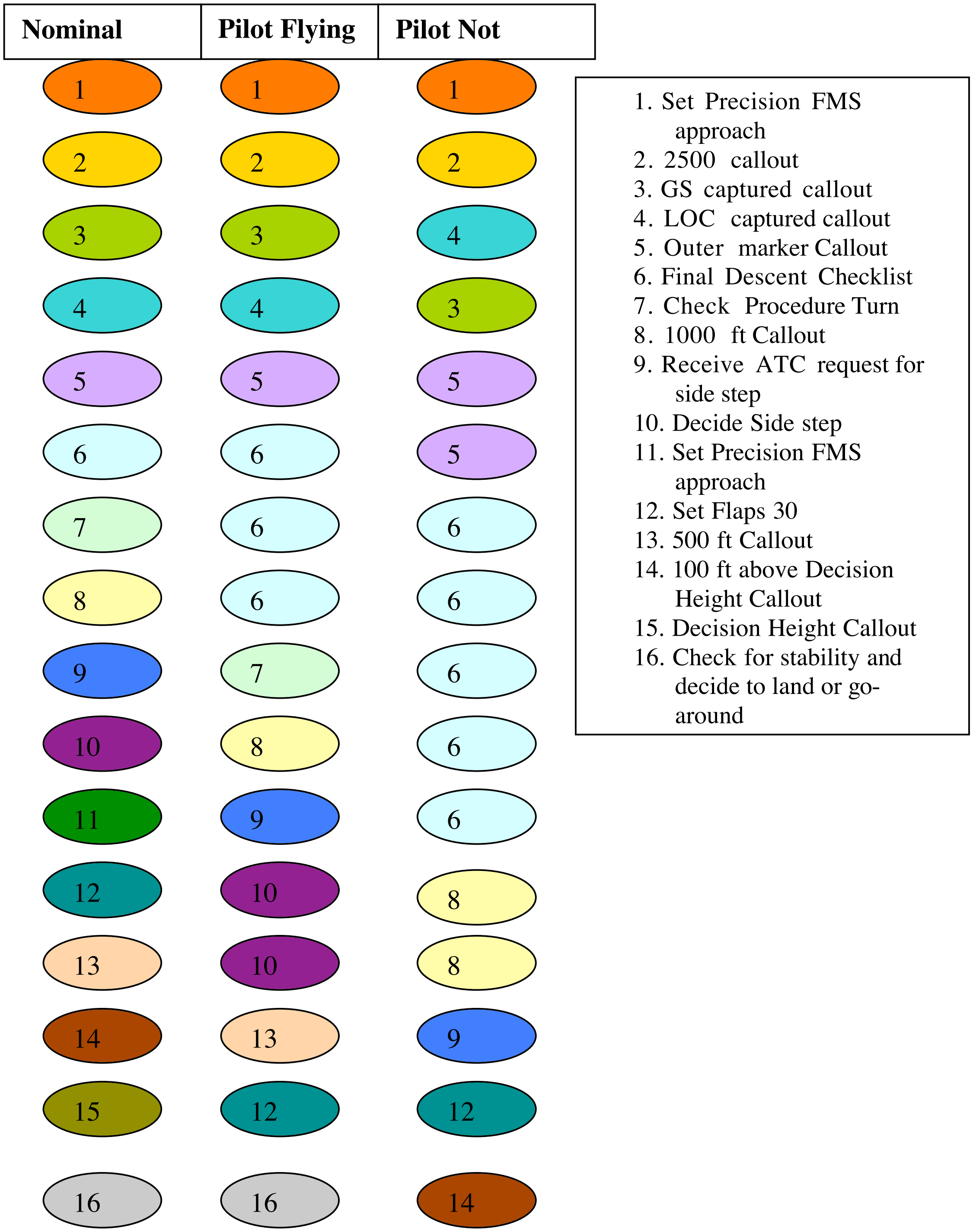

Figure 15. Goal Order for both Pilot Flying and Pilot Not Flying Sidestep Scenario with SVS (Scenario 8).

These data highlight the behavioral differences that exist between the three simulation environments programmed in the current simulation (Baseline without SVS condition, Baseline with SVS condition and the Sidestep Scenario with SVS). Behavioral changes begin to emerge when the operators are required to perform various procedural requirements in response to the environmental demands. Some of the required procedures are omitted, while others are flipped, and others still are extended. It is interesting to note that some cognitive and decision-making elements appear not to be completed. This lack of completion may lead to system vulnerabilities as the flight crew performing within the complex system appear not possess the cognitive resources to perform the activities. Goal ordering shows some evidence of early procedural completion by one of the flight crewmembers and a later completion by the other. This might suggest that one of the Air MIDAS operators may lack resources while the other Air MIDAS operator may possess sufficient resources to take over and assist the overburdened crewmember.

4 Discussion

The simulation experiment report provides support for the use of computational human performance models in system design and analysis. The validation effort provides evidence that the Air MIDAS tool with its constituent models of vision, audition, perception, attention, and its cognitive architecture generates behavior that is similar to human-in-the-loop performance. The performance differences that emerge in the current simulation provide insight into the simulation processes that could benefit from further work.

4.1 Simulation Data Generation Speed

The complexity of the operating environment and the level of detail required to update the worlds of the agents in the simulation resulted in slow computational performance in the data generation. We will explore methods to produce a more computationally efficient program.

4.2 Air MIDAS Model Development

There was a significant challenge involved in synchronizing the Air MIDAS equipment data with aircraft state/equipment data obtained from the NASA part task simulation. Goodman, Hooey, Foyle, & Wilson (2003) collected the simulation data every 10 ms, whereas the tick resolution used by Air MIDAS is 100 ms. As a result, there was effort involved in data reduction and data management to synchronize the part task simulation data with Air MIDAS model data.

The initial representation of the information accuracy function was the same for both the "non-directed" visual sampling, i.e. general scan, and for the "directed" information-seeking behavior. This rule was modified in our simulation runs to enable goal-directed behavior to always perceive information accurately.

4.3 Future Research Considerations

Visual target detection was noted as being a difficult task to incorporate into the human performance model. Landy (2002) provided equations to incorporate a model of target detection. Inclusion of this model would be a benefit for the modeling software and will be explored in future modeling efforts.

It also became apparent in working through the requirements to incorporate vision into a human performance model that representing human depth and distance is a significant challenge that will need to be addressed in the next phase of research in human-system simulation.

5 References

Atencio, A. (1994). Air Warrior MIDAS. [On-line]. Available. *http://caffeine.arc.nasa.gov/midas/original-midas/Air_Warrior.html.*

Atencio, A. (1998). Short Haul Civil Tiltrotor MIDAS. [On-line]. Available. *http://caffeine.arc.nasa.gov/midas/original-midas/Tiltrotor_MIDAS.html.*

Arditi, A. & Azueta, S. (1992). Visualization of 2-D and 3-D aspects of human binocular vision. Presented at the Society for Information Display International Symposium. The Lighthouse, Inc.

Balci, O. (1998). Verification, validation, and testing techniques. In J. Banks (ed.) Handbook of simulation: Principles, methodology, advances, applications, and practice, pp. (335-427), N.Y.: Wiley and Sons, Inc.

Corker, K. (2000). Cognitive Models & Control: Human & System Dynamics in Advanced Airspace Operations. In N. Sarter and R. Amalberti (Eds.) Cognitive Engineering in the Aviation Domain. Lawrence Earlbaum Associates, New Jersey.

Corker, K. (1994). Man-machine integration design and analysis system (MIDAS) applied to a computer-based procedure-aiding system. In *Proceeding of the 38th Annual Meeting of the Human Factors and Ergonomics Society.*□Human Factors and Ergonomics Society, Santa Monica, CA, October, 195-198.

Corker, K.M., Gore, B.F., Fleming, K. & Lane, J. (2000). Free flight and the context of control: Experiments and modeling to determine the impact of distributed air-ground air traffic management on safety and procedures. In *Third Annual Eurocontrol International Symposium on Air Traffic Management*, Naples, Italy, June 13-16.

Corker, K.M. & Guneratne, E. (2002). Human Factors Issues and Evaluation for Commercial and Business Aircraft Synthetic Vision Systems. HAIL Laboratory Report #SVS-2-2002. San Jose State University, San Jose Ca.

Gore, B.F. (2002). Human performance cognitive-behavioral modeling: A benefit for occupational safety. In B. Chase & W. Karwowski (Eds.), International Journal of Occupational Safety and Ergonomics (JOSE), 8 (3), 339-351.

Goodman, A., Hooey, B.L., Foyle, D.C., & Wilson, J.R. (2003). HPM-SVS part-task simulation documentation: Characterizing pilot performance during approach and landing with and without visual aiding. Moffett Field, CA: NASA Ames Research Center.

Landy, M.S. (2002). Vision and attention for Air Midas (NASA Final Report NCC2-5472). Moffett Field, CA: New York University, Dept. of Psychology and Center for Neural Science.

Law, A.M., & Kelton, D.W. (2000). Simulation, modeling and analysis (3rd Edition), N.Y.: McGraw Hill.

Lubin, J. & Bergen, J. (1992). NASA cockpit display visibility modeling project (NASA Final Report NAS2-12852). Moffett Field, CA: SRI/David Sarnoff Research Center.

McCracken, J.H. & Aldrich, T.B. (1984). Analysis of selected LHX mission functions: Implications for operator workload and system automation goals (Technical note ASI 479-024-84(b)). Anacapa Sciences, Inc..

Mumaw, R., Sarter, N., Wickens, C., Kimball, S., Nikolic, M., Marsh, R., Xu, W., & Xu, X. (2000). Analysis of pilot monitoring and performance on highly automated flight decks (NASA Final Project Report: NAS2-99074). Moffett Field, CA: NASA Ames Research Center.

National Academy Press (1990). Quantitative Modeling of Human Performance in Complex, Dynamic Systems. In S. Baron, D.S. Kruser, & B.M. Huey (Eds.), Panel on Human Performance Modeling, Committee on Human Factors, and the Commission on Behavioral and Social Sciences and Education, National Research Council, Washington, D.C.

Remington, R., Johnston, J. & Yantis (1993). Involuntary attentional capture by abrupt onset, Perception and Psychophysics, 51(3), 279-290.